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(54) Flowmeter

(57) A flow meter comprises a first section (1) and a second section (2) which includes ultrasonic transducers (T1, T2, T3, T4 and T5). The first section (1) includes a flow computer having means for flow measurement numerical processing and means for the generation of control and transmission waveforms. The second section (2) is connected to the first section (1) by a fibre optic link (3, 4, 5 and 6) and includes means for receiving said waveforms and for transmitting flow information. The transducers include transit time determining transducers (T1, T2), ultrasonic speed measuring transducer (T3), wall thickness measuring transducer (T4) and a temperature measuring transducer (T5). The control waveforms are used to select which transducer is to receive the transmission waveforms and thus which measurement is to be made.

FIGURE 1:- FLOW DETERMINING SYSTEM

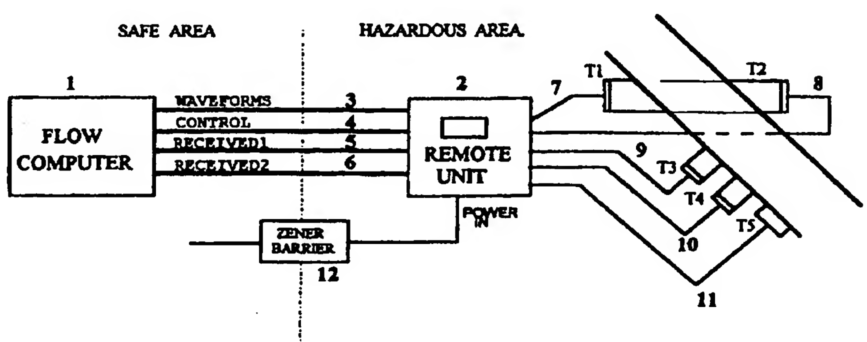

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FIGURE 1:- FLOW DETERMINING SYSTEM

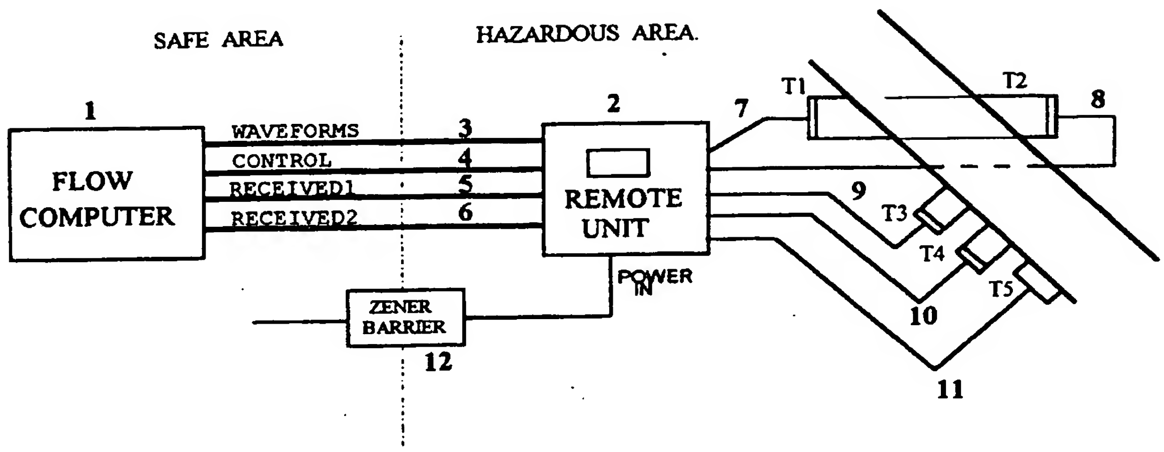


FIGURE 2:- BLOCK DIAGRAM OF REMOTE UNIT.

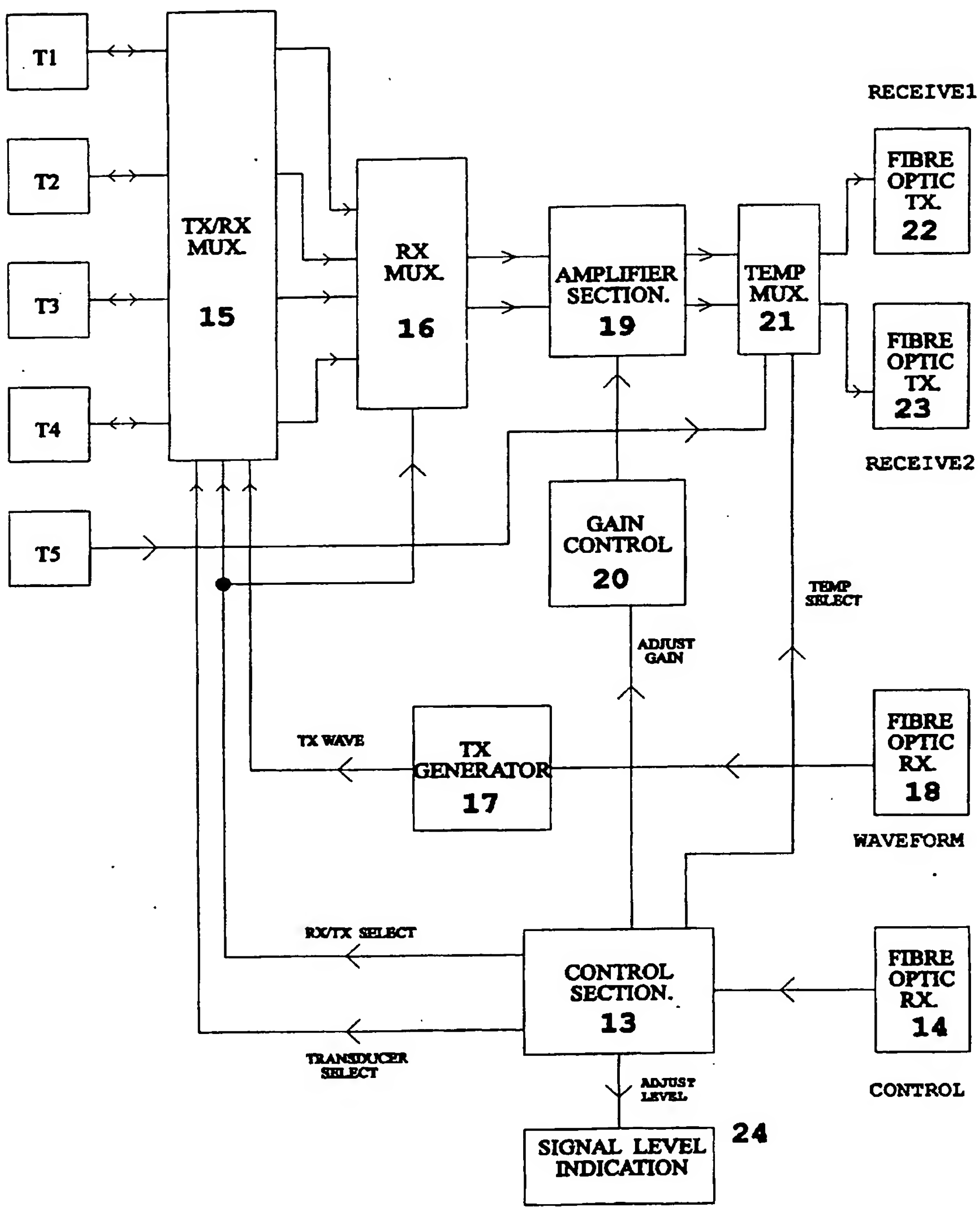


FIGURE 3:- FLOWCHART OF WALL THICKNESS MEASUREMENT.

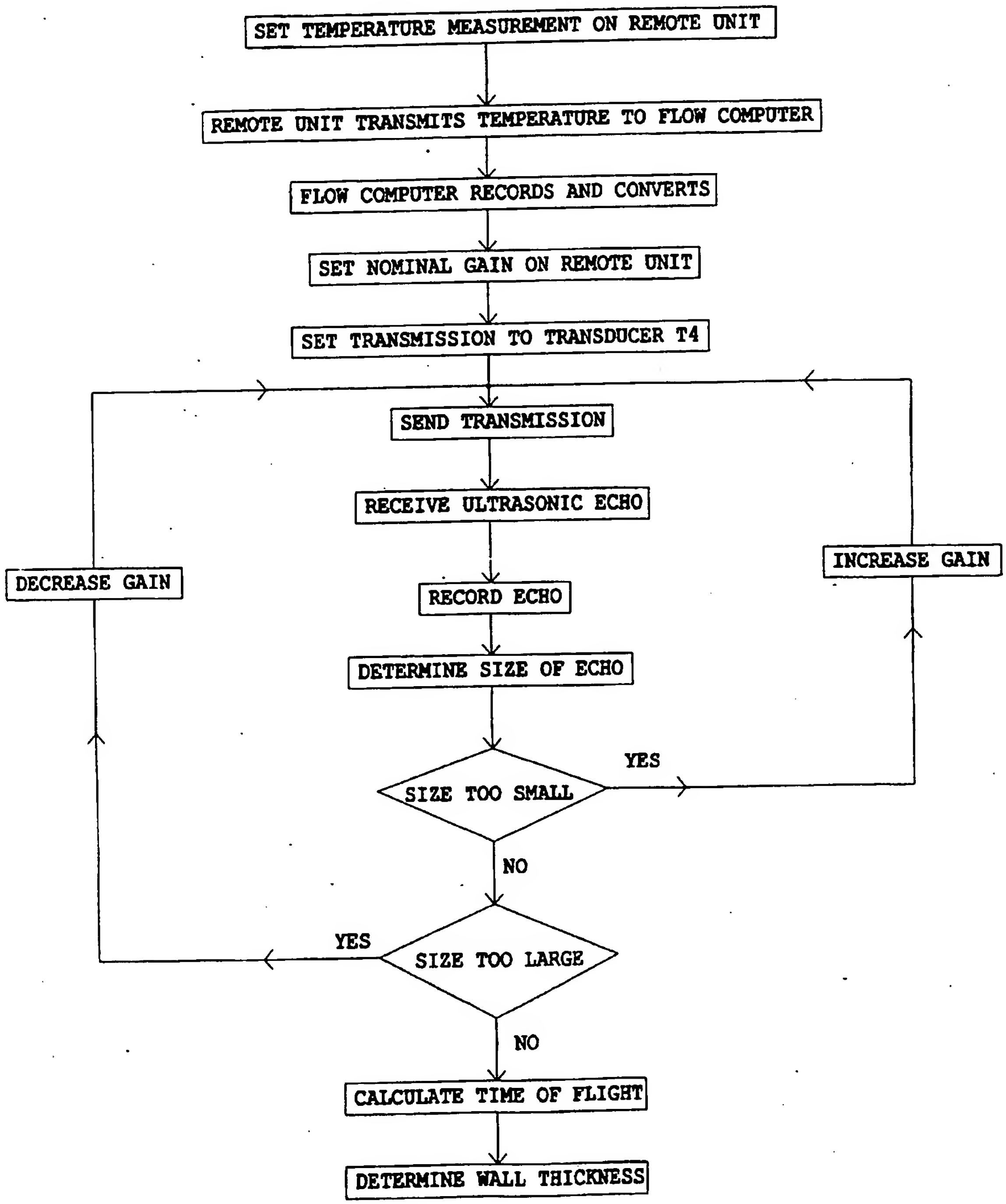


FIGURE 4:- FLOWCHART OF ULTRASOUND SPEED MEASUREMENT.

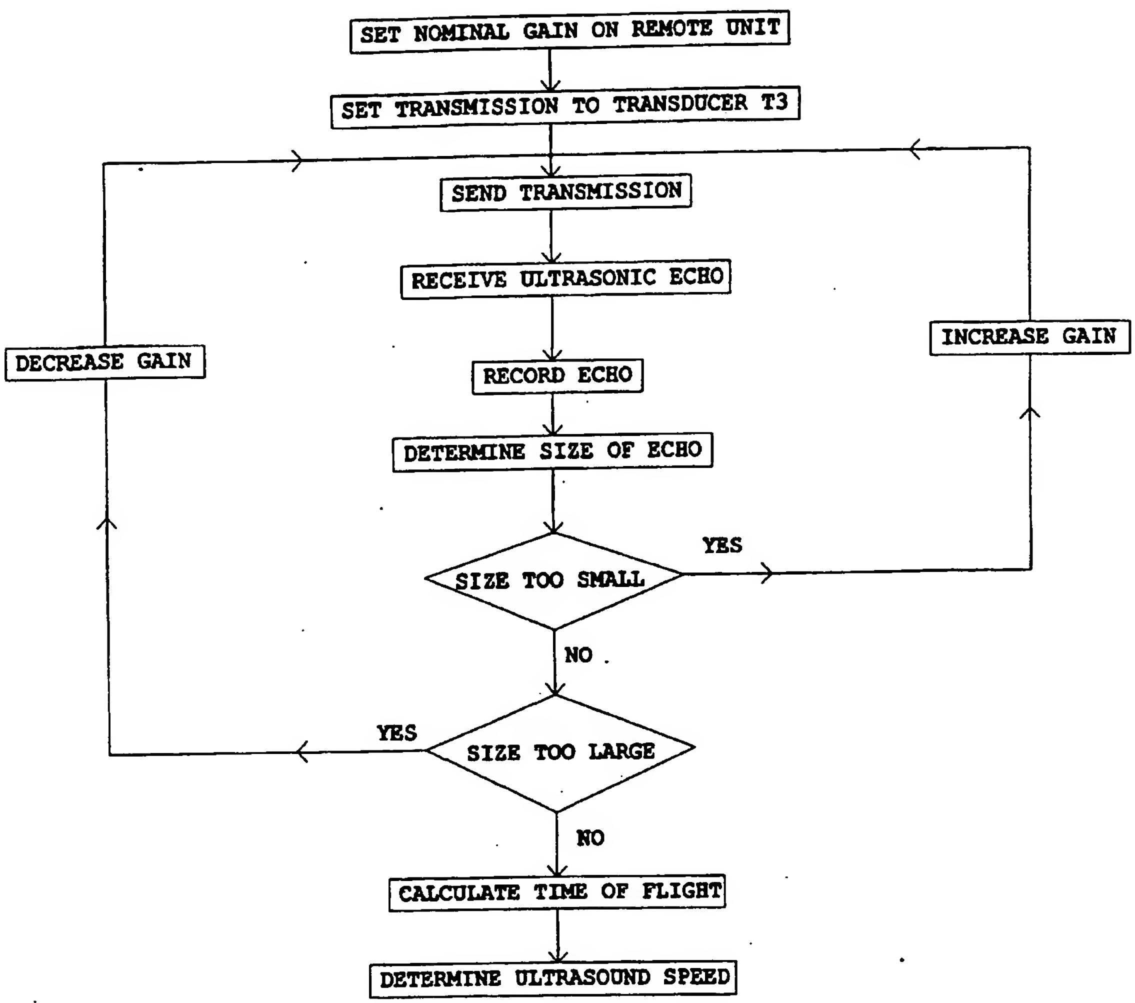


FIGURE 5:- TRANSIT-TIME DIFFERENCE

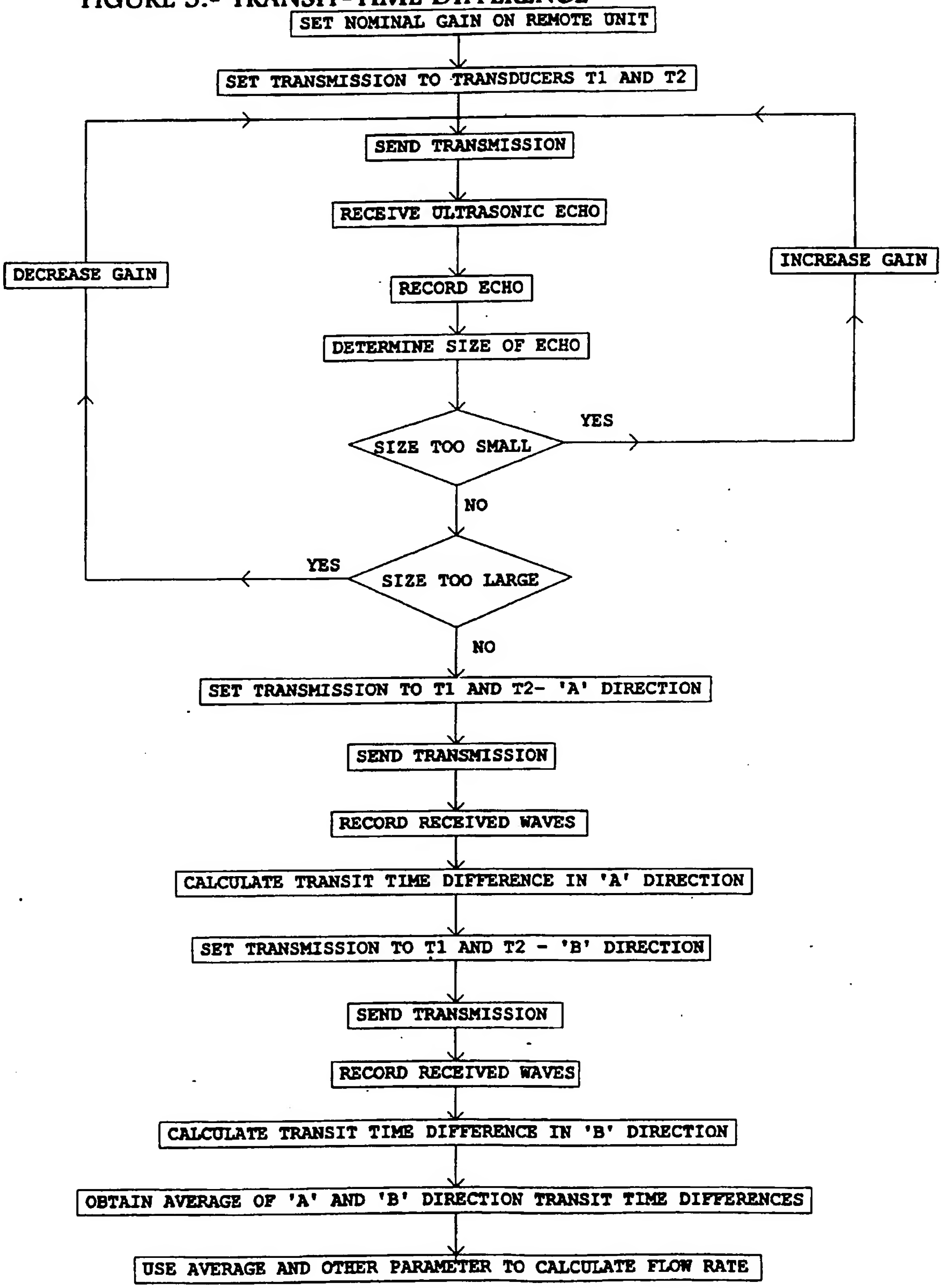
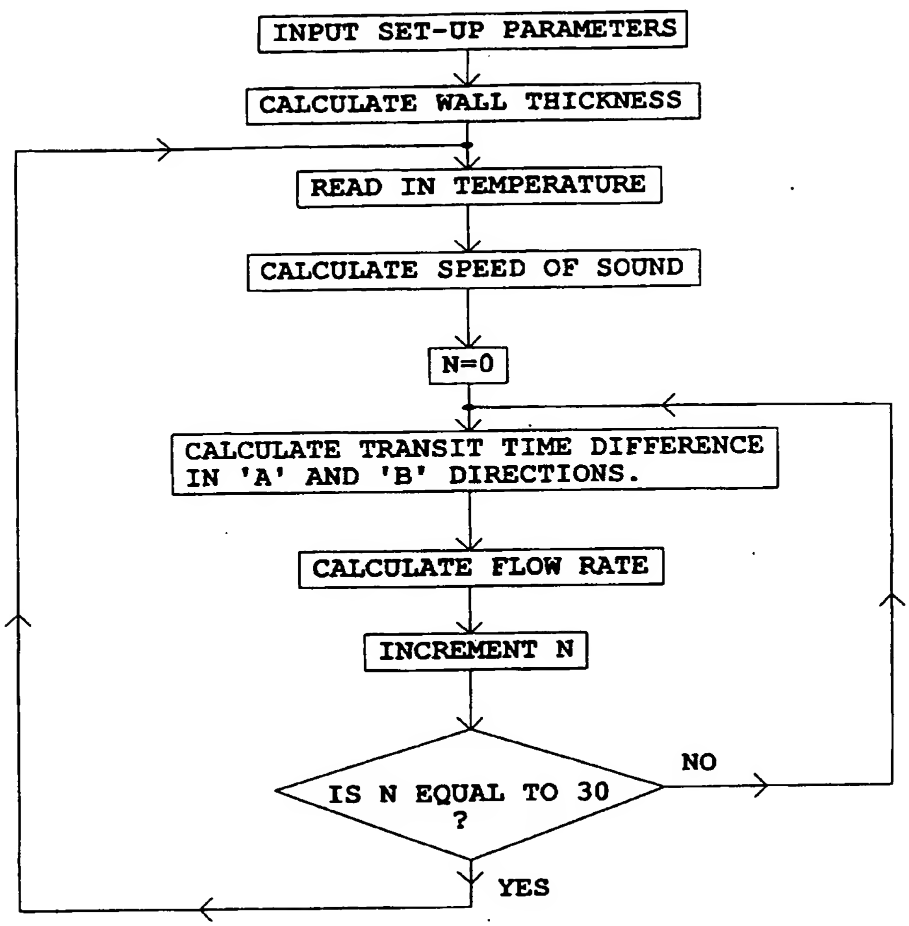


FIGURE 6:- FLOW CALCULATION SCHEME.



$$t := 0..(N-1-\tau)$$

$$ASDF_t := \frac{1}{N-\tau} \cdot \sum_t (x(t) - s(t+\tau))^2$$

Where $ASDF_t$ is the average squared difference function.

t represent units of time, at intervals of the sampling rate.

N is the total number of samples

x(t) is signal 1 (the "downstream signal"), which is a digital representation of a continuously varying function of time.

s(t) is signal 2 (the "upstream signal"), which is a digital representation of a continuously varying function of time.

τ is the time delay between signal 1 and signal 2 , at discrete intervals of sampling rate.

Figure 7. Comparing two signals using the Average squared difference function.

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FLOW METERS

Field of the Invention

This invention relates to flow meters and, in particular, to ultrasonic flow meters in which an ultrasonic wave is transmitted along a defined path through a medium, is detected by a transducer and the received waveform is analysed in order to determine the flow rate of the medium.

Such meters may include means for detecting the transit time of a wave along the path, or the difference between up-stream and down-stream transit times. The meters may also include means for detecting a Doppler shift of transmitted waves and/or means for providing total volumetric flow measurements.

The selection of appropriate instrumentation to monitor a given flow environment with a desired accuracy normally depends on a number of factors, including the purity, temperature, molecular weight and viscosity of the flowing medium, the approximate flow range and flow profile, plus the physical geometry and composition of the conduit or container.

A general survey of ultrasonic flow measurement systems is provided in the book entitled "Ultrasonic Flowmeters for Process Control; Theory, Techniques, Applications" by Lawrence C. Lynnworth, published in 1989 by Academic Press, Inc. to which reference should be made. All the above factors can thus be taken into account.

Despite, however, all the developments which have been made in relation to ultrasonic flow meters, there are no instruments currently available at economic prices which can be used to monitor flow effectively and reliably in a hazardous environment.

It is accordingly an object of the present invention to provide an improved form of flow meter for such purposes and an improved method of measuring fluid flow, which is applicable in a hazardous environment.

British Standard BS 5345 contains classifications of potentially hazardous environments, such as the potentially explosive environments which can be encountered in the petrochemical industry. The most dangerous zone is classified as zone 0, which is likely to contain combustible, explosive gas mixtures. A related British Specification (BS 5501 part 7, intrinsic safety) dictates the power restraints and other electrical and mechanical safety features of electrical and electronic equipment for use in zone 0.

Equipment that satisfies these conditions is referred to as "intrinsically safe" and the principle is that, if there is an explosive gas leak, the electrical power stored within the equipment will not be sufficient to ignite the gas. In practice, equipment that has intrinsic safety certification is placed in the zone 0 area, and a safety barrier (voltage and current limited) supplies the small amount of power allowed into such an area.

In many industrial processes where flammable materials are handled, any leak or spillage may give rise to an explosive atmosphere. To protect both plant and personnel, precautions must be taken to ensure that this atmosphere cannot be ignited. The areas at risk are known as "hazardous areas" and the materials that are commonly involved include crude oil and its derivatives, alcohols, natural and synthetic process gases, metal dusts, carbon dust, flour, starch, grain and fibres.

Control rooms are called "safe areas" and these contain mains equipment. It is possible for measuring devices in a hazardous area to communicate with dataloggers and computers in a safe control room over low speed loops and low speed digital data communications protocol.

Low-speed systems are, however, limited in application. For example, British Patent Specification No. 2 177 206 describes an ultrasonic flow meter which includes an intrinsic

safety barrier to permit measurements to be carried out in a hazardous area but the design of this flow meter is such that the rate at which measurements can be carried out is slow, the frequencies which can be used are only those less than 2 MHz and the application of such equipment is accordingly limited.

It is accordingly a more specific object of the present invention to provide an improved form of flow meter which enables high-speed measurements to be carried out.

Summary of the Invention

According to a first aspect of the present invention there is provided a flow meter which comprises a first section and a second section which includes transducers, the first section including means for flow measurement numerical processing and means for the generation of control and transmission waveforms, the second section including means for receiving said waveforms and for transmitting flow information.

Said first and second sections may be connected by a two-way fibre optic link. Alternatively, where measurements are being conducted in non-hazrdous environments, the two sections may be combined in one unit, which is provided with the requisite number of transducers.

The first section generates, in use, control and transmission waveforms which are passed by the fibre optic link to the second section. The second section responds to the control waveforms to, for example, select the transducers to which the transmission waveforms are to be directed. It then receives flow information from the transducers and passes this flow information either directly or via the fibre optic link to the first section which then carries out numerical processing operations.

When measuring the flow of, for example, a higly flammable fluid, the first section will normally be located in a safe area, whereas the second section can be located in a hazardous area, particularly a zone 0 area as defined above.

A range of transducers is preferably provided to obtain the information required to calculate the flow velocity. For a clamp-on system, at least two transducers placed at angles to the pipe are normally used to provide the flow information. An ultrasonic transducer placed normal to the pipe is preferably used to calculate the speed of ultrasound in the pipe. A further ultrasound transducer, again placed normal to the pipe, is preferably used to calculate the exact wall thickness of the pipe. A resistance temperature detector sensor is preferably used to measure temperature. For an invasive system, i.e. one in which the transducers are located within the pipe, it will,

of course, not be necessary to provide for measurement of the wall thickness of the pipe.

The first section preferably comprises a flow computer and the second section may be in the form of a remote unit which communicates with the flow computer via the fibre optic link. Alternatively, as indicated above, the first and second sections may be incorporated in a single unit.

In operation, control codes are sent by the flow computer to the remote unit to determine the mode of operation in which the remote unit is to be. Depending upon the current mode of the remote unit, the transmission waveforms from the flow computer are sent to a specific transducer or set of transducers, for example, one set for the flow information, one for the speed of ultrasound in the flowing medium, another for the wall thickness, etc. The same transducer(s) will then be used to receive the transmission echoes so that the flow information will be sent to the flow computer via the fibre optic link. The flow computer will thus build up the information required to calculate the flow velocity.

In traditional ultrasonic flow meters, i.e. those for use in non-hazardous areas, large pulses of energy have been transmitted in order to improve the signal to noise ratio. In power-limited applications, large pulses of energy are

prohibited so that such arrangements cannot be used in hazardous environments.

It is accordingly a further object of the present invention to provide a method of ultrasonic flow measurement which can be used in a hazardous environment and which enable a satisfactory signal to noise ratio to be obtained.

According to this aspect of the present invention there is provided a method of ultrasonic flow measurement which includes the use of a flow meter as defined above and in which the transmission waveforms transmitted via the fibre optic link have a relatively low voltage amplitude but are relatively long in length, the action of the first section being to reconstruct this waveform by comparing the two transit-time waveforms by correlation, compressing the received echoes into a waveform that has a large central peak.

The present invention further provides a method of ultrasonic flow measurement which includes the use of a flow meter as defined above and in which a reference signal is compared with a time delayed signal by introducing time shifts in the time delayed signal and optimising the mean square error between these two signals with respect to the introduced lag so as to minimise the normalised average squared difference function, as explained below.

Suitable waveforms which can be used include a linear frequency sweep, e.g. a Chirp signal, a non-random code, such as a "Frank Polyphase" non-random code, frequency-modulated waves such as 13-bit Barker, Golay and M-Sequence (pseudo-random) codes.

If upstream and downstream signals are generated simultaneously, the upstream and downstream received echoes are preferably directly correlated, as opposed to a method employing auto-correlation using a digital replica.

The present invention enables effective and reliable flow measurements to be carried out in a large variety of potentially hazardous environments and has particular application to the off-shore oil industry.

Brief Description of the Drawings

Figure 1 shows a flow determining system which includes a flow computer and a remote unit,

Figure 2 is a block diagram of the remote unit shown in Figure 1,

Figure 3 is a flowchart for wall thickness measurement,

Figure 4 is a flowchart for ultrasound speed measurement,

Figure 5 shows a method of calculating transit time difference,

Figure 6 shows a possible flow calculation scheme, and

Figure 7 illustrates the calculation of a normalised average squared difference function.

Description of the Preferred Embodiment

Figure 1 shows the arrangement of the various elements that make up the flow determining apparatus or flow meter. There is a flow computer 1 situated within the safe area of the environment. This is connected to a remote unit 2, which is within the hazardous area, by means of fibre optic cables 3 to 6. The hazardous area is hazardous because of, for example, the presence of highly inflammable gases or vapours. The remote unit 2 is also connected, via electrical cables 7 to 11 to a set of transducers T1, T2, T3, T4 and T5. These transducers T1 to T5 are mounted to the conduit through which the fluid to be monitored is flowing. A standard zener diode intrinsic safety barrier 12 is also included and it is through this barrier 12 that the power supply to the remote unit 2 is made.

In the particular arrangement shown in Figure 1, five transducers are mounted to the conduit. Transducers T1 and T2 are mounted at opposite sides of the conduit. They are

positioned thus in order to define an acoustic path through the flow of defined geometric dimensions. This mode of positioning is for use in clamp-on transit time flow measurements, i.e. time of flight ultrasonic flow measurements. Other arrangements of transducers T1 and T2 are also possible, as discussed in the Lynnworth articles referred to above. Other methods of calculating the flow are also possible using ultrasonic transducers, e.g. by using them to measure Doppler shifts or time delay correlation methods.

Transducer T3 is mounted normal to the wall of the conduit and is used to measure the speed of ultrasound through the medium contained within the conduit. This speed measurement may alternatively be carried out by means of transducers T1 and T2, in which case transducer T3 is not required.

Transducer T4 is also mounted normal to the wall of the conduit and is used to measure the wall thickness of the conduit. Transducer or sensor T5 is a resistance temperature detector (RTD) that is mounted at the wall of the conduit and is used to measure the temperature at this point.

The fibre optic cables 3 to 6 enable the flow computer 1 to communicate with the remote unit 2 which, in turn, communicates with the transducers T1 to T5. More specifically, transmission waveforms from the flow computer 1 are sent to the remote unit 2 via fibre optic cable 3 and control codes are

sent from the flow computer 1 via fibre optic cable 4. One of the functions of these control codes is to select the transducer or set of transducers to which the transmission waveforms are to be relayed.

When an ultrasonic waveform has been sent to a transducer or to a set of transducers and has been emitted into the fluid via the wall of the conduit by the selected transducer or set of transducers, a received signal from within the fluid is also received by the transducer or set of transducers. These received signals enter the remote unit 2 via cables 7 to 11. The remote unit 2 then amplifies these received signals and transmits the amplified signals to the flow computer 1 via fibre optic cables 5 and 6.

Figure 2 is a block diagram showing the hardware components that make up the remote unit 2. A control module 13 controls the operation of the remote unit 2 at any one time and it receives serial digital control codes from the flow computer 1 via a fibre optic receiver 14 which is connected to the 'control' fibre optic cable 4. The control module 13 selects the required function of the remote unit 2 in dependence on the control codes which it receives.

One of the functions of the remote unit 2 is to control which transducers or sets of transducers are connected to the TX_WAVE signal via an RX/TX multiplexer (MUX) 15. Similarly,

the control module 13 also controls which transducers are connected to a receiver amplifier section 19 via an RX multiplexer 16. A TX generator is used to boost the transmission waveforms received from the flow computer 1 via a fibre optic receiver 18 which is connected to the 'waveform' fibre optic cable 3. This is to provide sufficient drive to the ultrasonic transducers. The TX_WAVE signal is connected to the required transducer(s) via the RX/TX multiplexer 15.

During a waveform transmission, the control module 13, by use of an RX/TX select signal, will connect the required transducer(s) to the TX_WAVE signal via the RX/TX multiplexer 15, separating connection to the RX multiplexer 16 during this period. At the end of a transmission waveform, the required transducer(s) will be disconnected from the TX_WAVE signal and reconnected to the RX multiplexer module 16 by the same signal (RX/TX select).

The required transducer(s) will be connected via the RX multiplexer to the amplifier section 19 in order to amplify the received signals obtained from the transducers after the transmission. A gain control module is used to adjust the overall gain of the amplifier section so that the outputs from this section are within appropriate voltage limits. This gain adjustment is achieved by control codes sent from the flow computer 1.

The received signals are transmitted to the flow computer 1 via fibre optic transmitters 22 and 23 and the TEMP multiplexer 21. The TEMP multiplexer 21 is controlled by the 'temp select' signal which is asserted by the control module 13. During an ultrasonic transmission cycle, the outputs of the amplifier section 19 are connected to the fibre optic transmitters 22 and 23 by the TEMP multiplexer 21. But, when the flow computer 1 transmits the correct control codes to the remote unit 2, the RTD sensor T5 is connected to the fibre optic transmitter 22. In this way, the temperature information is sent to the flow computer 1 via the fibre optic cable 5.

Also included in the remote unit 2 is a signal level indication module 24. This is used during the installation of a clamp-on system. During such installation, the transducers T1 and T2 have to be positioned carefully so as to maximise the received waveforms. The flow computer 1 sends control codes to the remote unit 2 which uses the ADJUST_LEVEL signal to increase or decrease the signal on the signal level indication module 24. The installer can thus set up the clamp-on signal successfully by referring to the indication module 24.

For a transit time measurement using two transducers at angles to the conduit, the measurement methods are as follows:-

A) Wall thickness measurement.

In order for the flow determining system to calculate the flow of the fluid accurately, a measurement of the wall thickness of the conduit is necessary. Accurate knowledge of the wall thickness enables the flow computer 1 to determine the geometric properties of the acoustic path through the conduit and the contained fluid for the transmission of the ultrasound from transducers T1 and T2.

Figure 3 is a flowchart illustrating the method of measurement of the wall thickness and temperature measurement of the conduit. An explanation is as follows:-

a) The flow computer 1 first instructs the remote unit 2 to transmit the temperature information from transducer T5 by sending the appropriate code to the remote unit 2.

b) The remote unit 2 switches in the temperature circuit to transmit on optical fibre 5.

c) The flow computer 1 digitises the transmitted signal and converts this to obtain the temperature information.

d) The flow computer 1 sets a nominal gain on the amplifier section of the remote unit 2 by sending the relevant control code.

e) The flow computer 1 sets the remote unit 2 to transmit onto transducer T4.

f) The flow computer 1 now sends the transmission waveform to the remote unit 2 which, in turn, relays it to the transducer T4.

g) The echo from the opposite side of the conduit wall is received by the transducer T4 and is amplified by the amplifier section and is transmitted to the flow computer 1 via the optical fibre 5.

h) The flow computer 1 digitally records the received waveform from cable 5.

i) Using a digital processing method, the flow computer 1 determines the size of the received waveform. If the size of this waveform is too small for accurate calculations to be achieved, the gain of the amplifier section is increased and the process is repeated. Similarly, if the waveform is too large, the gain of the amplifier section is decreased and the process repeated and tested again.

j) Once a waveform of acceptable size has been received, the time of flight of the ultrasound wave is calculated. This may be effected by correlation, by envelope detection, or by any of the other techniques which are currently available.

k) When the time of flight has been determined, the wall thickness is calculated using this and the temperature information.

B) Speed of Ultrasound Calculation

The speed of the ultrasonic waves through the fluid is very important and this velocity is calculated using transducer T3. Figure 4 is a flowchart showing the method used to implement this calculation.

a) The flow computer 1 sends control codes to switch the remote unit 2 to transmit and receive using transducer T3.

b) The flow computer 1 sets a nominal gain on the amplifier section of the remote unit 2.

c) The flow computer 1 sends transmission waveforms to the remote unit 2 which relays them to transducer T3.

d) The echo from the opposite wall of the conduit is received by transducer T3, is amplified by the remote unit 2 and transmitted to the flow computer 1 via fibre optic cable 5.

e) The received waveform is digitally recorded by the flow computer 1.

f) The flow computer 1 determines the size of the received waveform by digital methods. If the size is too small, the gain of the amplifier section is increased (as above) and the process is repeated. Similarly, if the signal is too large, the gain is reduced and the process is repeated.

g) With a correctly sized waveform, the flow computer 1 calculates the time of flight of the wave by correlation, envelope detection or other available techniques.

h) The flow computer 1 calculates the speed of ultrasound in the fluid using entered data on the conduit dimensions, fluid parameters and the determined wall thickness.

C) Fluid Flow Calculation

With information on the wall thickness of the conduit and the speed of ultrasound within the fluid, the flow computer can now go on to determine the fluid flow within the conduit. In the transit time example, this involves use of both transducers T1 and T2, which are used to find the transit time difference between waves going up-stream to the flow and waves going down-stream to the flow. This may involve a method by which the electrical paths of received signals from transducers T1 and T2 can be swapped over, i.e. in one setting, the received signal from transducer T1 goes through the amplifier section and passes to the flow computer 1 on fibre optic cable 3, whilst

the signal from transducer T2 passes to the flow computer 1 via fibre optic cable 4. With the setting reversed, the signal from transducer T1 passes through cable 4 and the signal from transducer T2 passes through cable 3. In this way, small differences in the two electrical paths taken through the amplifier section and the cabling can be compensated for by calculating the transit time difference first with one setting and then with the other, and averaging the results.

Figure 5 is a flowchart showing a method of calculation of the transit time difference:-

a) The flow computer 1 sets the remote unit 2 to transmit and receive through transducers T1 and T2.

b) The flow computer 1 sets a nominal gain on the amplifier section of the remote unit 2.

c) Transmission waveforms are sent by the flow computer 1, received by the remote unit 2 and transmitted simultaneously by transducers T1 and T2.

d) Transducers T1 and T2 receive transmitted signals from across the conduit and the remote unit 2 transmits them to the flow computer 1 on fibre optic cables 3 and 4.

e) The flow computer 1 digitally records the waveforms.

f) The flow computer 1 digitally determines the size of the two waveforms.

g) The size of the received waveforms is checked and, if it is found to be too large, the gain of the amplifier section is turned down and, if it is too small, the gain of the amplifier section is turned up. The process is repeated until waveforms of acceptable size are received.

h) The flow computer 1 sets the remote unit 2 to transmit and receive to transducers T1 and T2 in direction A.

i) The transmission waveform is sent by the flow computer 1 to the remote unit which relays it to transducers T1 and T2.

j) The received waves are sent from the remote unit 2 to the flow computer 1.

k) The flow computer 1 digitises the waves.

l) The flow computer 1 calculates the transit time difference value in direction A by a process of cross-correlation in which the two echoes are directly correlated together.

m) The remote unit 2 is set to transmit and receive in direction B by the flow computer 1.

n) The transmission waveform is sent by the flow computer 1 to the remote unit 2 and on to the transducers T1 and T2.

o) The received waves are sent to the flow computer 1.

p) The flow computer 1 digitises the received waves.

q) The flow computer 1 calculates the transit time difference in direction B, again by cross-correlation as described above in relation to direction A.

r) The transit time differences in directions A and B are averaged and a flow rate value is then derived.

D) Measurement

The method explained above enables a single calculation of the flow rate to be achieved using the transit time method. The accuracy of this method can be increased by first taking the average of several received waveforms in both directions A and B. This has the effect of reducing the electrical noise content of these signals.

In a flow calculation scheme, the temperature and ultrasound velocity measurements would be up-dated periodically to track any possible variations and a possible transit time measurement scheme would then be as shown in Figure 6.

The flow determining system may use frequency modulated waveforms such as M sequence, Golay codes, pseudo-random or Barker codes. The system may also incorporate the use of linear frequency modulated chirp signals, i.e. non-random codes and matched non-linear frequency modulated chirp signals. A "Frank Polyphase" non-random code may also be employed.

In the specific arrangement shown in Figure 1, one pair of transducers, i.e, transducers T1 and T2, are used to measure the flow rate by clamp-on transit time measurement. The system may, however, also include the use of more pairs of transducers to measure the flow rate through different areas of the conduit. This will lead to more flow profile information becoming available and hence a better flow profile applied, particularly in distorted flow profile environments.

In addition to clamp-on arrangements, the invention is also applicable to invasive systems in which the ultrasonic transducers are mounted within the conduit and are in contact with the flowing medium as opposed to the outside wall of the conduit. Again, more than one pair of transducers can be used to obtain more flow profile information.

Figure 7 shows the use of a normalised average squared difference function as opposed to a correlation to carry out the required calculations. Thus, if two signals x(n) and s(n) are the same except for a relative time shift, as is the case

for the noisy reference signal and the noisy time delayed signal, one can introduce time shifts in the noisy time delayed signal with respect to the noisy reference signal and optimise the mean square error between these two signals. The basic difference between this method of calculation and correlation is that it involves taking the difference between two signals and squaring it, whereas a correlation system merely multiplies the two signals together.

In one particular application of the invention, two frequency-modulated ultrasonic signals are launched simultaneously into a flowing fluid in opposite directions with respect to the direction of flow, so that one signal travels upstream and the other signal travels downstream. The upstream and downstream transmissions propagate across the pipe at slightly different speeds and are thus received at minutely different times. The time difference is typically in the pico-second range.

A predetermined timing window allows the two signals to be digitised simultaneously, thus dividing the timing window into a series of smaller samples. After digitisation, the flow meter compares the upstream and downstream signals in either of two possible ways, the first of which is by direct cross-correlation and the second of which is by the "Average Squared Difference Method" described above with reference to Figure 7.

The transit time difference is then computed and is proportional to the fluid velocity. The frequency modulation can be pseudorandom, e.g. Barker or M Sequence, or purely deterministic, e.g. CHIRP or Frank Polyphase. As the two signals are transmitted simultaneously, they are perfectly synchronised when the two channels are digitised. The flow meter then computes the transit-time difference, and not the transit time. No accurate synchronisation between subsequent transmissions is, therefore, necessary and this simplifies the computation process.

Transit-time difference and time domain correlation can be used simultaneously when carrying out measurements in multi-phase conditions, i.e. when there are modest concentrations of gases or solids in a flowing liquid. This will further enhance the accuracy of the overall flow measurement.

Claims:-

1. A flow meter which comprises a first section and a second section which includes transducers, the first section including means for flow measurement numerical processing and means for the generation of control and transmission waveforms, the second section including means for receiving said waveforms and for transmitting flow information.

2. A flow meter as claimed in Claim 1 in which, said first and second sections are connected by a two-way fibre optic link.

3. A flow meter as claimed in Claim 1, in which at least two transducers placed at angles to a pipe are used to provide the flow information.

4. A flow meter as claimed in Claim 1, in which at least one transducer placed at an angle to the flow ois used for time domain correlation.

5. A flow meter as claimed in Claim 1, in which an ultrasonic transducer placed normal to the pipe is used to calculate the speed of ultrasound in the pipe.

6. A flow meter as claimed in Claim 3, in which a further ultrasound transducer, again placed normal to the pipe, is used to calculate the exact wall thickness of the pipe.

7. A flow meter as claimed in any one of the preceding claims, in which a resistance temperature detector sensor is used to measure the temperature of the flowing medium.

8. A flow meter as claimed in Claim 2, in which the first section comprises a flow computer and the second section is in the form of a remote unit which communicates with the flow computer via the fibre optic link.

9. A flow meter as claimed in Claim 8, in which the second section includes means which respond to the control waveforms to select the transducers to which the transmission waveforms are to be directed.

10. A method of ultrasonic flow measurement which includes the use of a flow meter as claimed in any one of the preceding claims.

11. A method as claimed in Claim 10 as appendant to Claim 2, in which the first section is located in a safe area and the second section is located in a hazardous area.

12. A method as claimed in Claim 11, in which the transmission waveforms transmitted via the fibre optic link have a relatively low voltage amplitude but are relatively long in length, the action of the first section or flow computer being to reconstruct this waveform by comparing the two transit-time waveforms by correlation, compressing the received echoes into a waveform that has a large central peak.

13. A method as claimed in any one of Claims 10 to 12, in which the waveforms which are used include Chirp signal, frequency-modulated waves such as 13-bit Barker, Golay and M-Sequence (pseudo-random) codes.

14. A method of measuring fluid flow which includes the simultaneous transmission of upstream and downstream signals and comparison of the two received signals to determine the difference in transit time between the upstream and downstream signals.

15. A method as claimed in Claim 14, in which the transit time difference is determined by direct cross-correlation.

16. A method as claimed in Claim 14, in which the transit time difference is determined by the "Average Squared Differences Method".

17. A method of measuring the rate of flow of a multiphase fluid which includes the simultaneous use of transit-time and time domain correlation.

18. A flow meter comprising first and second sections constructed and arranged to operate substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

19. A method of measuring flow substantially as hereinbefore described with reference to Figures 1 to 6 of the accompanying drawings.

20. A method of measuring flow substantially as hereinbefore described with reference to Figure 7 of the accompanying drawings.

The Patent Office

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Application No: GB 9608532.9
Claims searched: 1-13

Examiner: David Summerhayes
Date of search: 8 July 1996

Patents Act 1977
Search Report under Section 17

Databases searched:

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UK Cl (Ed.O): G1A (APG), G1G (GPKT, GPKX), G1N (NAHJA), H4B (BK, BK8, BK12, BK24, BKJ)

Int Cl (Ed.6): G08C 23/00, 23/06

Other: ONLINE: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB2177206A	(BESTOBELL)	1,3,10,11 at least
X,&	WO94/12960A1	(SIEMENS) - see corresponding US patent 5453866	1,2,8,10, 11 at least
X	WO92/14227A1	(ROSEMOUNT) - see particularly p.4, lines 3 & 4	1,2,8,10, 11 at least
&	US5453866	(GROSS)	
X	US4810891	(MASCHEK)	1,2,8,10, 11 at least

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